1. You are the giving officer on a submerged submarine. Twenty men move from the crew's mess, 20 ft forward of the ship's center of gravity to the forward torpedo room, 180 ft forward of the ship's center of gravity. How much water must be pumped off to shift the center of gravity to the after trim tank (70 ft aft of the center of gravity) to compensate for the weight shift, if the average weight of the men is 165 lbs?

\[ 20(165 \text{ lb})(180 + 10) = (x \text{ lb})(175 + 20) \]

\[ x = \frac{495,000}{395} \]

\[ x = 1,260 \text{ lb} \]
2. A submarine with a submerged displacement of 5200 ft³ has a trim of 16 ft and a freeboard of 14.2 ft. How much variable ballast must be transferred from the after trim tank to auxiliary tank #1 to correct for a trim angle of 1.5° by the bow, if the distance between the tanks is 110 ft?

\[
\begin{align*}
BC &= \frac{16}{110} \cdot 14.2
\end{align*}
\]

\[
\begin{align*}
\Delta &= \frac{BC}{\tan 1.5°}
\end{align*}
\]

\[
\begin{align*}
\Delta &= 0.4998 \text{ ft}
\end{align*}
\]
3. A mini-sub has the following characteristics:

- LOA = 250 ft
- B = 16 ft
- Δ_{A,B} = 3000 LT
- Δ_{S,C} = 2500 LT

LCL of the even buoyant hull is 71 ft forward of A.P.

VCL of the even buoyant hull is 6.7 ft aft of A.P.

Δ_{A,B} = 300 LT, Δ_{B,C} = 250 LT, arranged as shown.

a. Find LCB in the submerged condition.

b. Find VCB in the submerged condition.

c. Find ISG.
### Part A

**LCB = LCL**  

<table>
<thead>
<tr>
<th>Moment</th>
<th>Unit</th>
<th>MM</th>
<th>MCG</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBT #1</td>
<td>200</td>
<td>25</td>
<td>4050</td>
<td></td>
</tr>
<tr>
<td>MBT #2</td>
<td>200</td>
<td>15</td>
<td>3000</td>
<td></td>
</tr>
<tr>
<td>MEL</td>
<td>2500</td>
<td>72</td>
<td>120,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5000</td>
<td></td>
<td>225,000</td>
<td></td>
</tr>
</tbody>
</table>

**LCB**  

\[
\text{LCB} = \frac{225,000}{3,000} = 74.5 \text{ ft} \text{ of AP + LCB}_{\text{sub}}
\]

---

### Part B

**UBA sub**  

<table>
<thead>
<tr>
<th>Moment</th>
<th>Unit</th>
<th>MM</th>
<th>MCG</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBT #1</td>
<td>300</td>
<td>8</td>
<td>2600</td>
<td></td>
</tr>
<tr>
<td>MBT #2</td>
<td>500</td>
<td>4</td>
<td>1100</td>
<td></td>
</tr>
<tr>
<td>MEL</td>
<td>2500</td>
<td>9</td>
<td>12,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3500</td>
<td></td>
<td>21,000</td>
<td></td>
</tr>
</tbody>
</table>

**UBA**  

\[
\text{UBA} = \frac{2600 + 1100}{3000} = 0.93 \text{ in} \text{ AP + WBA = UB}_{\text{sub}}
\]

---

### Part C

**UB C**  

<table>
<thead>
<tr>
<th>Moment</th>
<th>Unit</th>
<th>MM</th>
<th>MCG</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBT #1</td>
<td>300</td>
<td>6</td>
<td>7500</td>
<td></td>
</tr>
<tr>
<td>MBT #2</td>
<td>500</td>
<td>6.2</td>
<td>15,500</td>
<td></td>
</tr>
<tr>
<td>MEL</td>
<td>3500</td>
<td>9.2</td>
<td>19,900</td>
<td></td>
</tr>
</tbody>
</table>

**UB C**  

\[
\text{UB C} = \frac{7500 + 15,500}{3000} = 8.5 \text{ ft}
\]

\[
\overline{DC} = \frac{\overline{UB} - \overline{BC}}{2} = 8.5 - 6.5 = 2.5 \text{ ft} \text{ of AP + DC}
\]
4. a. $C_p = \frac{\nabla \cdot A}{L \cdot T \left( \frac{A}{2} \right)^2} = \frac{SS(S)}{(500)(450)(1)} = \frac{0.619}{C_p}$

4. Expressions for $C_{ush}

\[ E_{HP} = \frac{\xi}{5} \left( \frac{\xi}{5} \right)^3 \left[ (C_{ush} + C_A) S_{BH} + C_{ush} S_{RA} \right] \]

\[ E_{HP} = \frac{\xi}{5} \left( \frac{\xi}{5} \right)^3 \left[ C_{ush} S_{BH} + C_A S_{BH} + C_{ush} S_{RA} \right] \]

\[ S_{BH} = C_4 \cdot \text{BA} \cdot DL \]

\[ C_4 = 1.01 \left( \frac{C_p}{\xi} \right)^{1/2} = 0.799 \]

\[ S_{BH} = (0.799)(5) \left( \frac{450}{500} \right) = 73.89 \text{ ft}^2 \]

\[ \frac{E_{HP}}{\xi} = \frac{S_S^4}{\xi^3} \left( C_{ush} S_{BH} + C_A S_{BH} + C_{ush} S_{RA} \right) \]

\[ \frac{S_S}{\xi} = \frac{C_{ush} S_{BH} + C_A S_{BH} + C_{ush} S_{RA}}{E_{HP} \cdot \xi} \]

\[ \frac{E_{HP}}{\xi} \left( \frac{S_S^4}{\xi^3} \right) = \frac{C_{ush} S_{BH} + C_A S_{BH} + C_{ush} S_{RA}}{E_{HP} \cdot \xi} \]

\[ \frac{S_S}{\xi} = \frac{C_{ush}}{E_{HP}} \left( \frac{S_S^4}{\xi^3} \right) \]

\[ C_{ush} = \frac{552.13}{(500)(504) + 17,028.9} \]

\[ \frac{E_{HP}^2}{\xi^3} = \frac{67.76 \%}{(46.023 + 4)} \]

\[ C_{ush} = \frac{0.012017 \cdot E_{HP}^2}{\xi^3} = 0.000147 \]
C. ESTIMATE MAX SPEED.

\[
E_{mp} = (2.31e)(t_0) = (93,000)(0.75) = 39,000 \text{ ft}.
\]

\[
C_{mph} = \left[ 1 + 0.5 \left( \frac{t_0}{2} \right)^3 + 3 \left( \frac{t_0}{2} \right)^3 \right] \frac{0.075}{(log R_e - 2)^2}
\]

\[
C_{mph} = \frac{0.07975}{(10^2) - 2}, \text{ R.H.S. of Eqn. (4)}
\]

\[
0.07975 = 0.012007 \frac{E_{mp}}{v^2} - 0.000147
\]

\[
0.07975 = \frac{3.6031}{v^2} + 0.000147 = 0
\]

**R.H.S. Eqn. to degree**, for values of \( v \approx 3.5 \text{ km/hr} \).

<table>
<thead>
<tr>
<th>( R_e ) in ft</th>
<th>( \frac{\text{ft}}{v} )</th>
<th>( \frac{\text{ft}}{v^2} )</th>
<th>( \text{R} )</th>
<th>( E_{mph} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>50.64</td>
<td>1.415 ( \text{ft}^2 )</td>
<td>-0.0016</td>
<td>0.0079</td>
</tr>
<tr>
<td>40</td>
<td>27.52</td>
<td>1.9 ( \text{ft}^2 )</td>
<td>-0.0067</td>
<td>0.0077</td>
</tr>
<tr>
<td>55</td>
<td>29.06</td>
<td>1.663 ( \text{ft}^2 )</td>
<td>-0.0007</td>
<td>0.0076</td>
</tr>
<tr>
<td>60</td>
<td>60.77</td>
<td>1.71 ( \text{ft}^2 )</td>
<td>+0.0006</td>
<td>0.0079</td>
</tr>
</tbody>
</table>

Choose \( v_{mph} \approx 35.5 \text{ kt} \).